So Unfair it's Fair: Equipment handling in remote versus in-person introductory physics labs

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While understanding laboratory equipment is an important learning goal of physics laboratory (lab) instruction, previous studies have found inequities as to who gets to use equipment in in-person lab classes. With the transition to remote learning during the COVID-19 pandemic, class dynamics changed and the effects on equipment usage remain unclear. As part of a larger effort to make intro physics labs more equitable, we investigated student equipment usage based on gender and race in two introductory physics lab courses, one taught in-person and one taught remotely. We found inequities between men and women for in-person instruction, replicating previous work with a new student population. In contrast, we found that remote instruction created a more gender equitable learning environment, albeit with one student typically in charge of the equipment per class session. When we looked at equipment handling based on student race, we found no inequities in either format. These results suggest that changes should be made in introductory labs to create a more gender equitable learning environment and that some aspects of remote labs could help make these labs more equitable.

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I. INTRODUCTION

Instructional physics laboratories (labs) are an important part of undergraduate curricula where students learn science's exploratory nature [1]. A major component of these physics labs is experience with equipment. Competency with various instruments and equipment is a common recommended learning outcome and vital for the success of physicists in academia and industry alike [2, 3].

Surprisingly, very little research has probed the relationship between hands-on equipment usage and the development of technical equipment skills or other learning outcomes. The closest studies come from comparing the efficacy of virtual and hands-on labs. For example, one study found that computer simulations were just as effective for teaching equipment skills and physics concepts as hands-on experience with physical lab equipment [4].

Equipment handling, however, has been connected to students' physics identity [5, 6]. For example, using equipment gives students a method to both obtain and exhibit authority [7]. This authority allows students to be taken seriously and have their ideas recognized [8], which contributes positively to student identity [9–11]. Overall, this identity development improves retention and encourages students to continue pursuing a career in physics [12].

Despite its importance, not everyone gets equivalent usage of this equipment. Previous studies have found that women, on average, use equipment less than men in introductory physics labs [5, 13–16]. Tinkering with equipment is often viewed as a masculine activity, which leads to students expecting men to use equipment across various physics contexts [17]. While no studies have yet investigated equipment usage based on race or ethnicity, minoritized students face various inequities in physics [18–20]. Because racialized identity complicates physics identity development [21, 22], we should be concerned that equipment handling could also be inequitable along race/ethnicity lines.

The above discussed work, however, has focused on (in)equities during in-person instruction. With the shift to remote learning during the COVID-19 pandemic, lab structure was completely changed. Many instructors shipped students equipment, had students use materials around their houses or dorm rooms, or used videos and simulations [23]. Because of this stark difference, remote instruction's effects on equipment usage remain unclear. While previous studies of remote labs have looked at various indicators of student understanding [24–26] and interactions [27], none that we are aware of have yet investigated how the changes affected student equipment usage or issues of equity. As institutions continue to explore options for remote and hybrid instruction, it is important to gain a better understanding of student equipment handling in these learning environments.

In this paper, we investigate how student equipment usage differs between in-person and remote instruction. Additionally, we study how this frequency differs for students based on gender and race. We look at our data with an equity-based lens, where we define equity as equal access to the learning environment [28] and therefore equal usage of lab equipment. While differences across demographics might appear for individual class sessions, an equitable learning environment means these differences even out across the entire semester.

II. METHODS

A. Course Structure and Data Collection

We analyzed video data from the lab component of two introductory calculus-based mechanics courses (from an engineering and majors sequence) at Cornell University. A greater proportion of physics and engineering physics majors were enrolled in the majors sequence than the engineering sequence (61% and 3%, respectively). Students who self-identified as women made up approximately 50% of both course sequences. The majors sequence had a slightly lower proportion of minoritized students than the engineering sequence (21% and 29%, respectively). The in-person data were from one class section from the engineering sequence. The remote data were from three class sections: two from the engineering sequence (16 students) and one from the physics sequence (9 students).

There were minimal curriculum differences between the labs for the engineering and majors sequences. The sequences were primarily different in the non-lab component of the course, where the sequences had separate lecture and homework material. Since the data did not differ systematically between the sequences, we merged the two sequences' data sets. The lab component was inquiry-based and comprised of several units, each wherein students investigated a unique phenomena. Students in the remote courses constructed their experimental set-ups using items they had at home, akin to the courses discussed by Moosvi *et al.* [25], in contrast to the shared equipment available in the in-person labs. For both courses, the lab was responsible for 10% of the course's final grade and students only worked on the lab during the class period. Students typically worked in groups of three or four and submitted collaborative lab notes by the end of the session, which were graded by their TAs. Each group member shared the same grade for the lab notes. The grading scheme provided no particular reward or incentive for a student to use or not use the equipment.

Most units were two class sessions long. Students changed groups every unit for the in-person class, but groups were fixed for nearly the entire semester in the remote version. This change in group composition approach was largely due to the COVID-19 pandemic. Rather than supporting students in getting to know and learning how to work with different peers, as with the in-person labs, the instructional team hoped that maintaining static groups in the remote labs would provide students with more social supports.

For the in-person video data, we analyzed recordings that were used in previous studies [29, 30]. The in-person students did not receive compensation for participating in the study because participation did not require any activity beyond the normal instructional tasks. For the remote video data, students recorded videos of their lab group's breakout room on Zoom and shared it with researchers. Students in the remote course were incentivized to participate in the study with $5 for each class session.

The final data set included 19 students for the in-person modality and 25 for the remote modality. Demographics were self-reported in a survey distributed at the beginning of the semester, which also asked for student consent to participate in the study (see Table I). Students in our data set exclusively self-identified as men or women. For this reason, we will only be investigating gendered differences in equipment usage between men and women. Based on standard definitions and our data set, we sorted students' race into white, Asian/Asian American, and minoritized. We acknowledge that our broad categorization of minoritized students fails to account for their unique experiences [31], but allows us to maintain student anonymity. For similar reasons we do not probe the intersection of race and gender in equipment usage.

TABLE I. Self Reported Student Demographics. Students that reported identifying as multiple races are counted in each category.

Category	In-Person	Remote	Total
Total Number	19	25	44
Men	11	14	25
Women	8	11	19
Asian/Asian American	7	5	12
Black/African American	1	1	2
Hispanic/Latino	5	3	8
White/Caucasian	8	17	25
Prefer Not to Disclose	1	1	2

B. Processing the data

After collecting the video, we had three researchers code for student equipment usage by looking at student activity in 5 minute intervals, as done in Refs [14, 32]. We counted equipment usage as any instance where a student was handling equipment. This includes everything from measuring a pendulum string with a ruler to holding a ball that is dropped to investigate air resistance. If a student was clearly using a phone to collect data, such as using it as a timer to record the period of an oscillation, it was coded as equipment. If it was not clear what they were using their phone for, it was not coded.

A limiting factor in our analysis is that remote video data came from student laptop cameras which do not provide a full view of student workspaces. At certain points, students may have worked off-screen and – because we only coded equipment usage when we were reasonably certain – may have not been coded. Instances where students were active, off-screen, and not vocally describing their work, however, were uncommon. As a result, this would not have significantly impacted our results. Another limitation is that we collected video data from only a handful of student groups from one type of in-person lab and one type of remote lab. We cannot necessarily generalize results to all in-person and remote labs.

C. Data Analysis

First, we found the percentage of coded 5-minute intervals that each student spent using equipment per class session (*percentage equipment usage*). We did this calculation to account for groups spending varying amounts of time on the lab. Because certain labs involved more equipment usage than others, we converted the percentages of equipment usage to z-scores based on each class session. As in Equation 1, the z-score (z_i) gives, for each student in session i, a measure of how their percentage equipment usage (x_i) compared to the average usage for that class session ($\bar{x}_{\text{session}}$), in units of standard deviation of equipment usage that session (σ_{session}) [33].

$$z_i = \frac{x_i - \bar{x}_{\text{session}}}{\sigma_{\text{session}}} \quad (1)$$

While the data shows the same patterns before being transformed into z-scores, the conversion allows the differences across the semester to easily be shown in aggregate. These z-score calculations were separated between remote and in-person, as the two classes had very different usage statistics. Data were plotted so that each data point is a single student on a single day (i.e. each student is multiple data points in the plots). We treat these data points as independent because student lab usage each week is typically independent of what they did the previous week [14].

Our definition of equity as equal usage of lab equipment indicates that the average z-score for all students should be zero if the learning environment is equitable. Because the remote and in-person distributions have different shapes and both the means and distributions provide valuable insight into equipment usage, there is no apt statistical test to compare the groups. Instead, we will be commenting on the both the means and distributions.

Lastly, we evaluated the extent to which students varied in their equipment usage each session. We calculated, for each student, the standard deviation of their equipment usage across sessions. Large standard deviations represent a large change in equipment usage and small standard deviations represent little to no change in equipment usage.

FIG. 1. Frequency of student equipment usage throughout the semester, sorted by class format and gender. This plot is a sideways symmetric histogram where the width represents the density of the number of data points. The dots indicate the means and the bars denote standard uncertainties.

FIG. 2. Standard deviation of each student's equipment usage across the semester, sorted by class format.

III. RESULTS

When we compare equipment usage z-scores across the in-person and remote classes as in Fig. 1, one first result stands out. For the in-person class, the equipment usage distributions are fairly normally distributed. For the remote classes, however, the distribution is significantly positively skewed. This difference in distribution shapes is most likely due to the availability of tools for students in these formats. For the in-person classes, every student had equipment available to them in the classroom and students shared a workspace. For the remote courses, however, students made their experimental set-ups with what they had at home. This resulted in most groups having one student handle all equipment for a class session. Occasionally, groups would split measurement equipment tasks among the whole group. For example, one student made a pendulum while other members timed the period.

Our definition of equity means the average equipment usage z-score for all student groups is zero. When investigating men and women in each format, we see that equipment usage became slightly more equitable in the remote format. As seen in Fig. 1, women used equipment less than average for in-person instruction and more than average during remote instruction, getting closer to an average z-score of zero. Men's equipment usage was above average in the in-person labs and decreased to below average in the remote labs, though slightly closer to an average z-score of zero. The distributions of equipment usage for the first recorded lab sessions were similar to the full semesters' distributions for both courses, suggesting that the (in)equities were present at the beginning of the semester.

We also investigated the variation in each student's equipment usage throughout the course, Fig. 2. In the remote course, there was an approximately uniform distribution of students whose equipment usage varied drastically (large standard deviation) or minimally (small standard deviation) across the course of the semester. For the in-person course, however, very few students had a high variation throughout the semester, meaning most students did not change their equipment usage between sessions.

We found no discernible differences in equipment usage for either instructional method based on race/ethnicity (Fig. 3). However, we must note that we have a small data set of minoritized students: $N = 6$ for in-person instruction and $N = 4$ for remote. Because of this small data set, we cannot draw strong conclusions for minoritized students.

IV. DISCUSSION

We found that in-person instruction had inequitable differences in equipment usage for men and women. Across the entire semester, men used equipment more than average while women used it less than average. This pattern is in line with previous studies [5, 13–16, 34], now expanded to a course of primarily engineering majors and with a nearly equal proportion of men and women. Interestingly, this inequity was present even in the first lab session. We also found that most students changed their equipment usage very little between lab sessions.

When we investigated the remote version of the lab, both men and women's equipment usage was closer to equitable (z-score equal to zero). Compared to the in-person labs, relative equipment usage increased for women while decreasing for men. The distributions for the first lab sessions did not differ from the full semester distributions. In addition, a greater

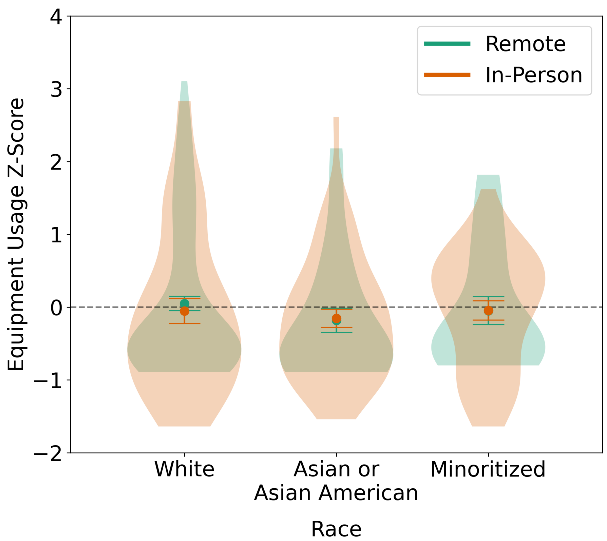

FIG. 3. Frequency of student equipment usage throughout the semester, sorted by class format and race.

proportion of students varied their equipment usage between sessions compared to students in the in-person labs. These results suggest that some change in the format of the remote labs made the course more equitable.

For remote instruction, because students had to construct labs at home or in their dorm rooms, one student typically built the experimental set-up per session. Thus, the remote labs were inherently inequitable, as per our definition: many students did not have access to the learning environment. We hypothesize that this blatant inequity caused students to more explicitly negotiate their roles even from the first lab session, leading to more equitable equipment handling. Additionally, students had fixed groups for the semester for the remote course. Students knew coming into class each week what their teammates had done the previous week. Therefore, when one student would handle all the equipment for one session, the group members would intentionally discuss the following week who would be responsible for the experimental set-up. This is supported by the larger number of students with high variation in equipment usage in the remote labs – many students were frequently changing their roles. Ultimately, the dynamic was visibly biased towards a single student handling equipment within each individual session so students worked to make it more fair ("so unfair, it's fair").

For in-person labs, however, no role negotiation must occur because everyone *could* access the equipment. Furthermore, groups changed every unit for the in-person course so students would not know what their new group members did the previous week unless they discussed it. Previous studies found that students do not explicitly discuss their roles week-to-week; rather, they happen "naturally" [14, 35]. Because most students' equipment usage for the in-person course did not vary significantly across the semester, students were likely falling into roles with which they felt comfortable or confident. Students who believe they are better with equipment may actively exclude their partner from using the equipment [5], so there could be gendered views causing the exclusion of women from handling equipment [34].

These results suggest that making in-person labs more structured, such as to explicitly negotiate roles, could alleviate inequities. This is in line with previous work that found increasing structure improves equity in lecture courses [36, 37]. By trying to compensate for the difficulties of remote learning, students created a more structured learning environment through the direct and explicit communication required. For in-person labs to address these inequities, they might need to facilitate discussions among students that otherwise would not occur. For example, instructors could have students decide what roles they will handle for an entire class session before beginning the lab and to ensure those roles are rotated between sessions. Based on our data, static groups throughout the course may also support equity through explicit role negotiations.

When looking at race, we see no significant differences in equipment usage between instructional methods. Interestingly, the distribution for minoritized students for the in-person labs is negatively skewed, suggesting the minoritized students in in-person labs may have been high equipment users in more lab sessions than their white or Asian/Asian American peers. Future work should explore whether this skewed distribution replicates with a larger data set.

V. CONCLUSIONS

We analyzed student equipment usage from video data of the lab component of an introductory calculus-based mechanics course taught remotely and in-person. Results indicate that the remote labs created a more equitable learning environment for men and women. However, there is no indication that remote labs are more or less equitable based on race or minoritized status. Future analyses will extend investigation of in-person labs with a larger data set to see what trends emerge with assigned groups and a greater population. Additionally, future studies will investigate the effect of group gender and racial composition on student equipment usage.

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